#22
Letter
S.Davis
7/11/02

FAX COVER SHEET

Nixon & Vanderhye P.C.
ATTORNEYS AT LAW
1100 NORTH GLEBE ROAD, SUITE 800
ARLINGTON, VIRGINIA 22201-4714

TELEPHONE: 1-703-816-4006
FACSIMILE: 1-703-816-4100

FAX COPY RECEIVED
JUL 2 2002
TECHNOLOGY CENTER 2800

TO:	Examiner Wai Sing Louie 703 305 0474
FIRM:	PTO Art Unit 2814
FAX NO:	703 308 7722
DATE:	July 2, 2002
FROM:	Arthur R. Crawford
PAGES:	16 (including this sheet)
YOUR REF:	Appln of Nagahama et al Serial No. 09/500,288
OUR REF:	925-179

MESSAGE

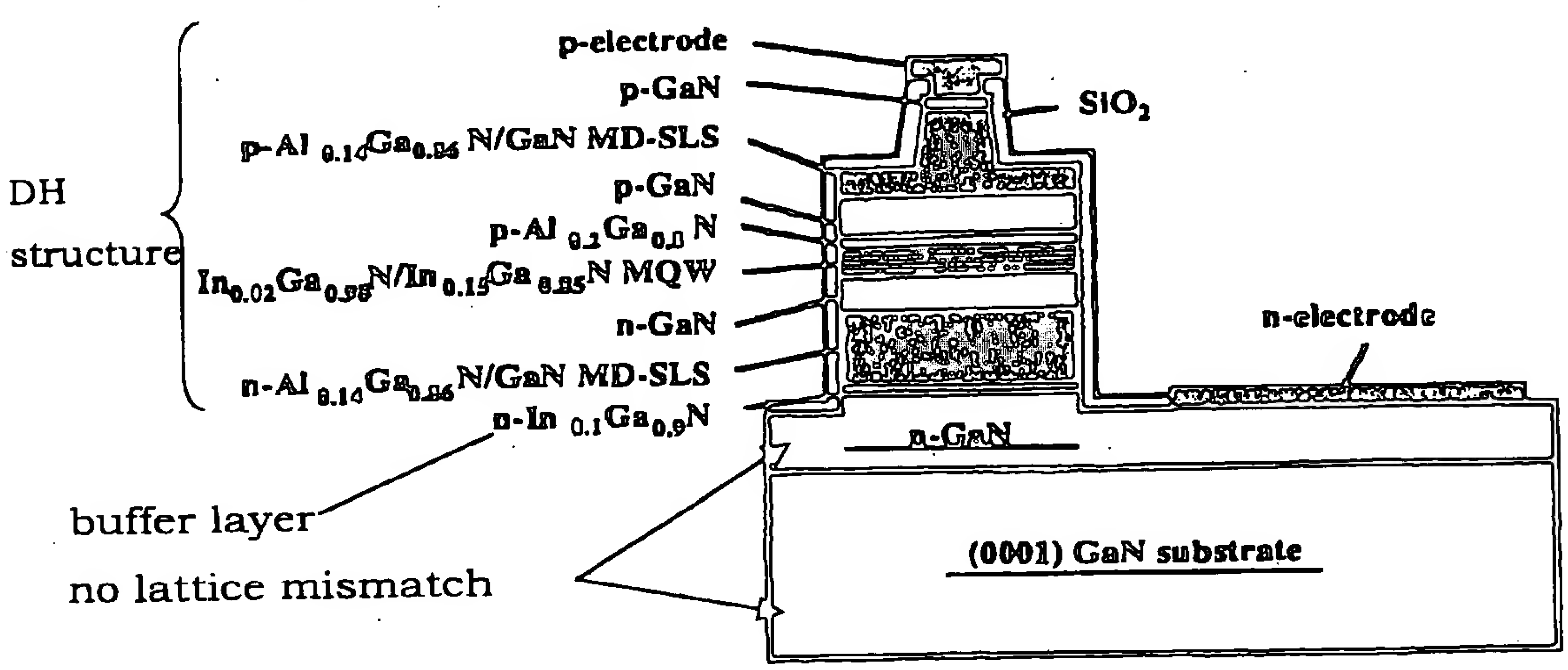
Attached are copies of the materials I intend to discuss with you in person on Tuesday, July 9th at 10:00 AM

Previous Proposals

(1) a laser structure on a GaN substrate

In a conventional nitride semiconductor laser, since crystallinity of an active layer or cladding layer significantly influences the lifetime of the device, the GaN layer is normally formed on a GaN substrate before forming the active or cladding layers. This is because the GaN layer, which has inherently the same lattice constant and coefficient of thermal expansion as the GaN substrate, had been thought to grow with only a few defects on the GaN substrate. For example, Nakamura in Jpn.J.Appl.Phys., Vol.37(1998), Pt.2, No.3B, pp.L310 discloses a structure of a GaN-based laser as shown below, where a GaN layer is first grown on a GaN substrate and, then, an n-type cladding layer, an active layer and a p-type cladding layer (= Double Hetero or "DH" structure) are formed on the GaN layer intervening an InGaN buffer layer.

S. Nakamura, Jpn.J.Appl.Phys., Vol.37(1998), Pt.2, No.3B, pp.L310, Figure2 (see page 1, lines 16-26)



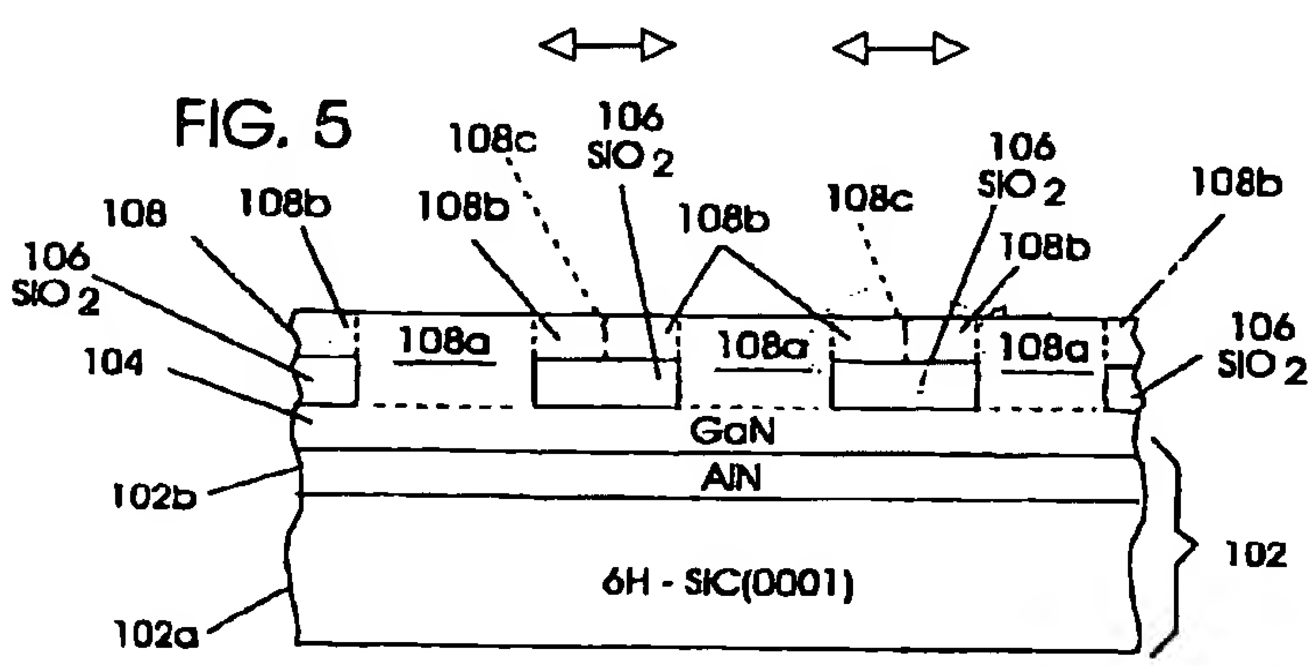
642912

(2) a laterally grown GaN substrate

As an effective method for forming a low-dislocation-density GaN substrate, the lateral-growth process is known to those skilled in the art. For example, Davis (US 6,051,849) and Koide(JP11-145516) disclose such a technique. Davis describes laterally growing GaN over strip-shaped SiO_2 masks. Koide describes laterally growing GaN from stripe-shaped GaN layers. In both cases, the dislocation density of the GaN layer is lowered in the areas where the GaN has grown in a lateral direction.

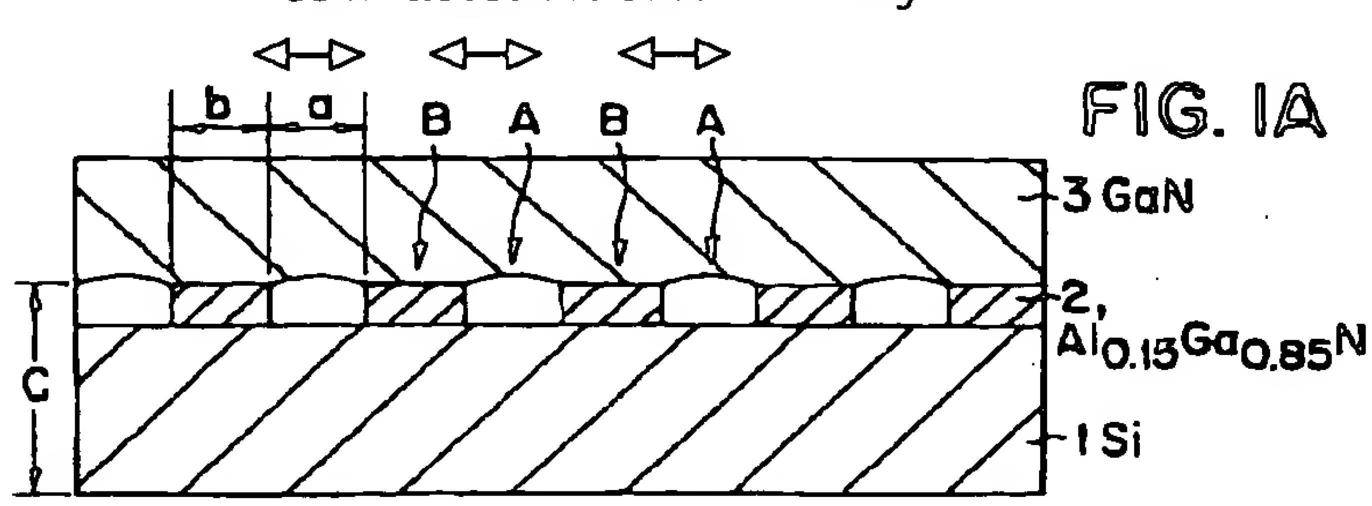
<u>Davis, Fig. 5</u>

low dislocation



<u>Koide, Fig. 1</u>

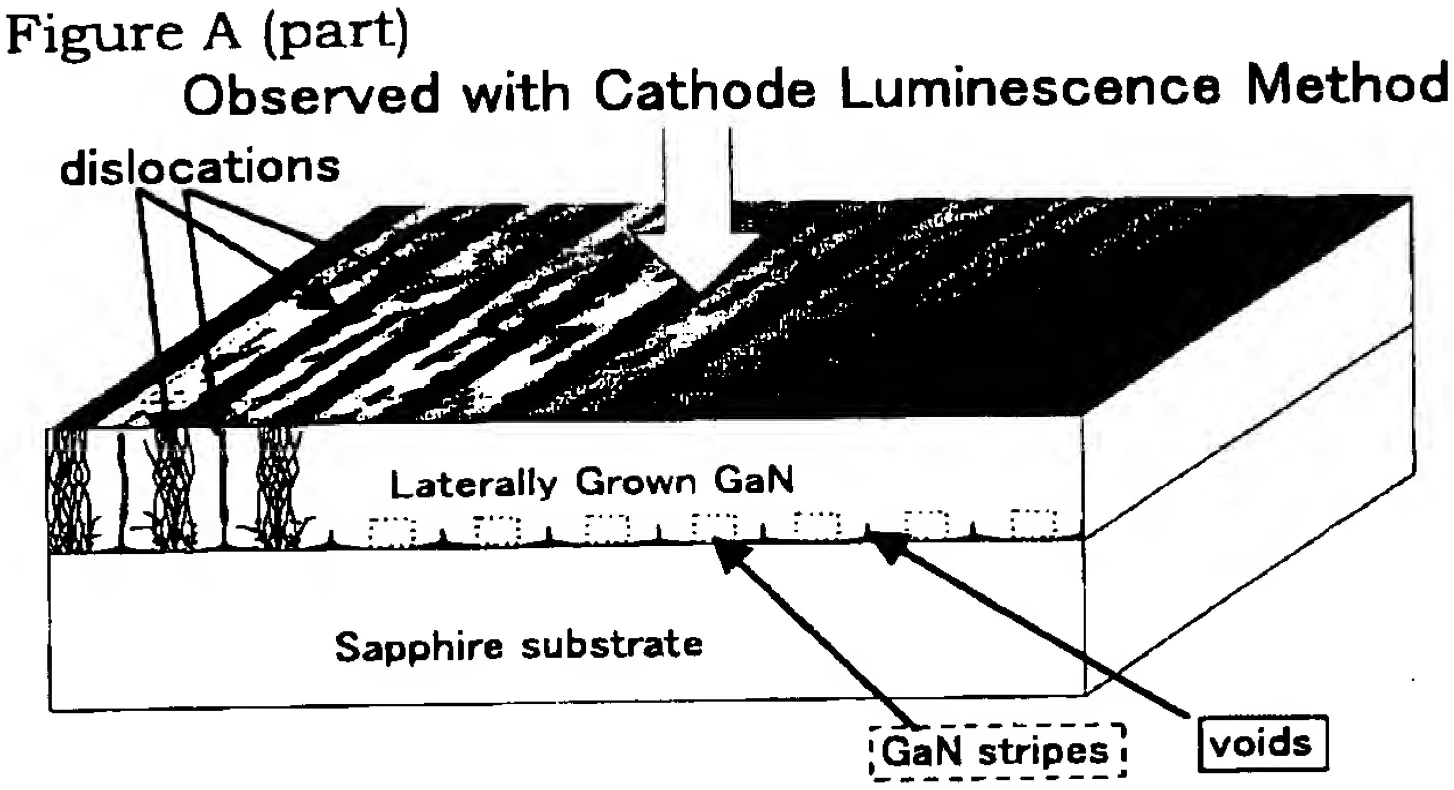
low dislocation density



Cathode luminescence observation of a laterally-grown GaN substrate would clearly show the effect of depressing dislocation density. Fig. A (below and attached in color) shows a cathode luminescence photograph of a GaN substrate that is made by a process

similar to that of Koide. In Fig.A, dislocations are only observed in the area just above the stripe-shaped GaNs and on the lines where two laterally-grown GaNs are joined.

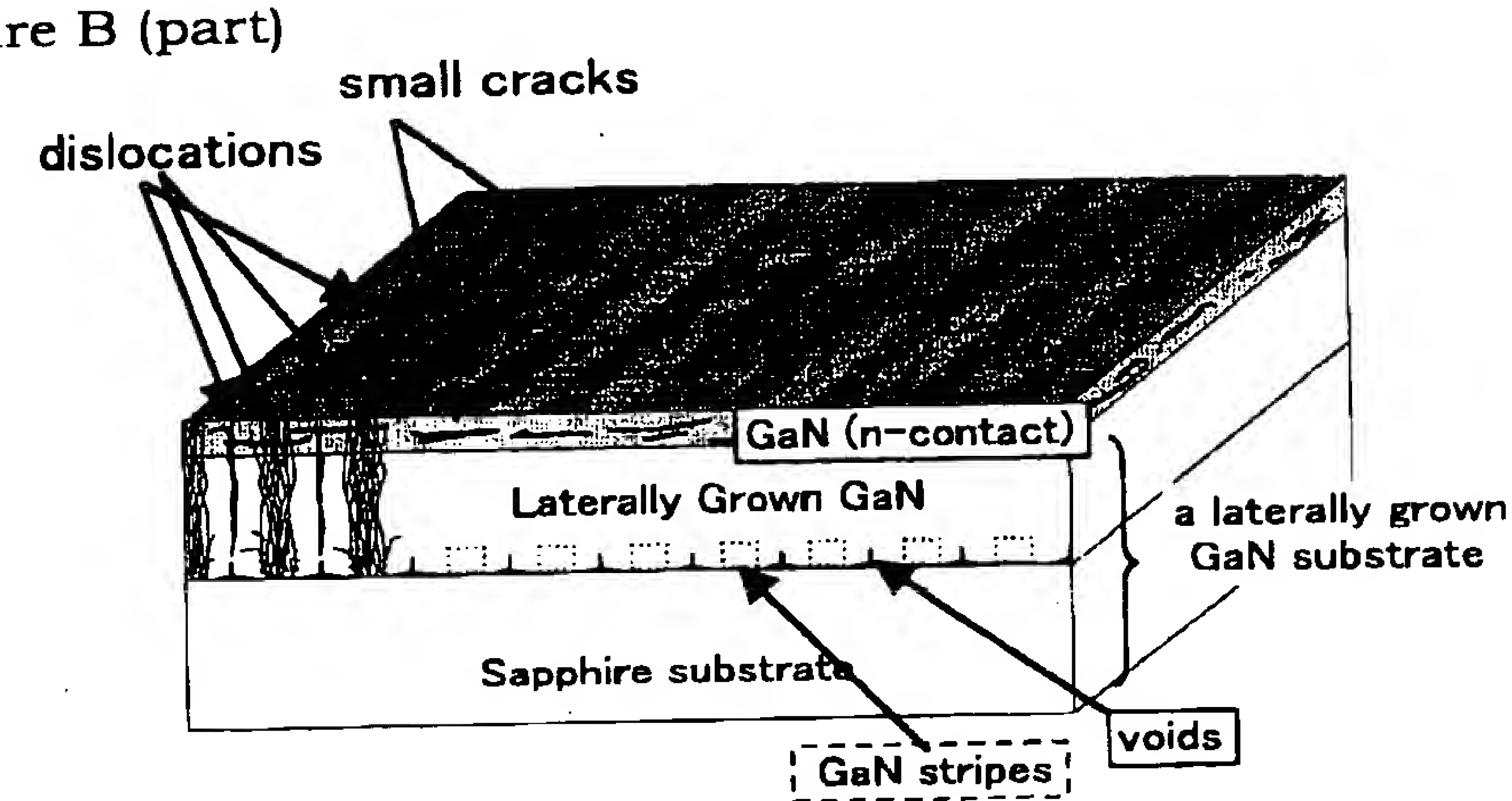
Figure A (part)



The present invention solves these problems in the prior art

Contrary to what is generally taught in this art, the present inventors have found that, in the case of a GaN substrate grown through a "lateral-growth process", an unique phenomenon occurs -- when a GaN layer is formed on a laterally grown GaN substrate before forming a DH structure like conventional nitride lasers, extremely small cracks tend to occur in the GaN layer. (see Figure B and attached, in color).

Figure B (part)



642912

It is surprising that small cracks tend to occur in the GaN layer formed on the GaN substrate that has the same lattice constant and thermal expansion coefficient. For example, if a GaN layer is formed on a normally grown GaN substrate, such cracks do not appear (see Figure C attached).

Applicants believe that the occurrence of "small cracks" is a specific phenomenon for a laterally grown GaN substrate. These "small cracks" shows a unique behavior. For example, the "small cracks" grows in a parallel direction to the growing surface of a crystal, while dislocations propagate in a perpendicular direction. Also, the "small cracks" exist not on the surface but in the interior of the GaN layer.

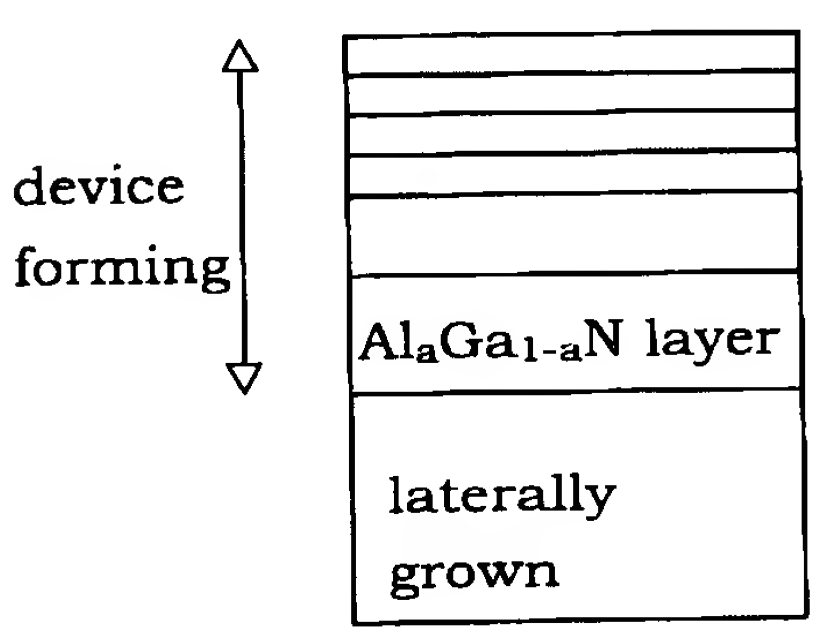
The problem of these small cracks had not been known to those skilled in the art until the present inventors found the phenomenon. This is because the "small cracks", unlike well-known defects (cracks or dislocations), can hardly be observed by a traditional optical microscope observation or even a TEM observation. The cracks can be observed only with a fluorescence microscope or by a cathode luminescence method.

The present invention

Unlike the prior art, in the present invention an AlGaN layer instead of a GaN layer is formed on the GaN substrate before the other layers are formed, as illustrated below with regard to claims 9 and 14.

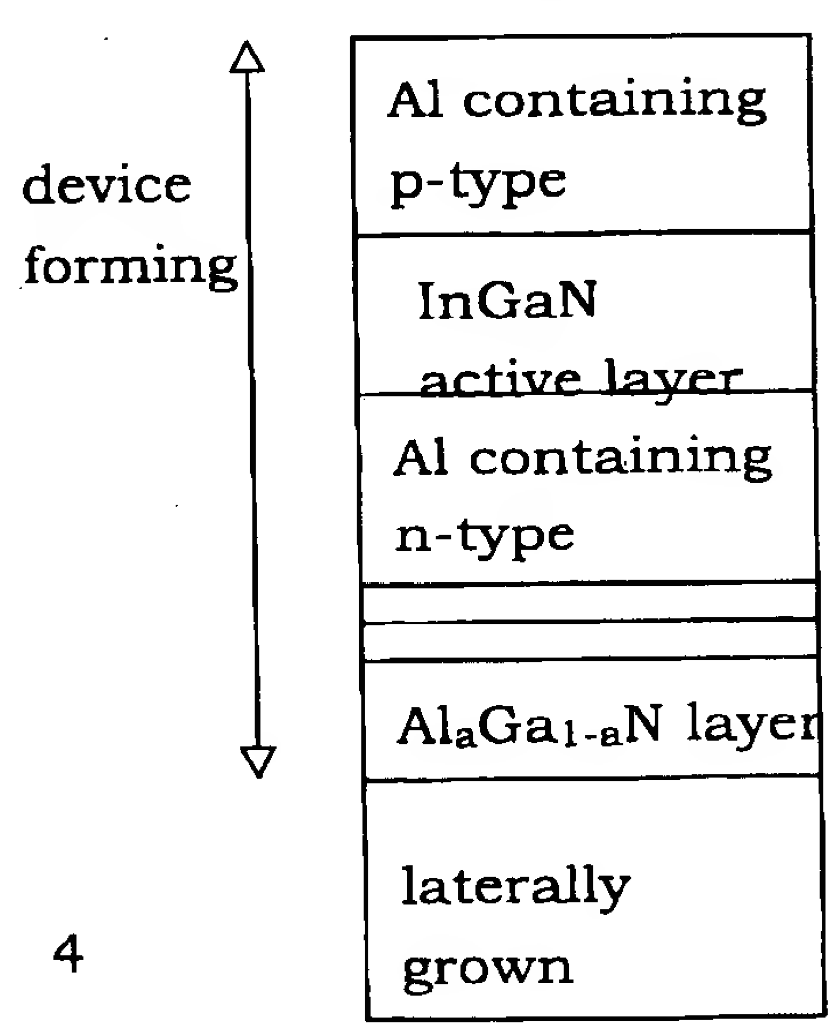
claim 9

nitride semiconductor laser



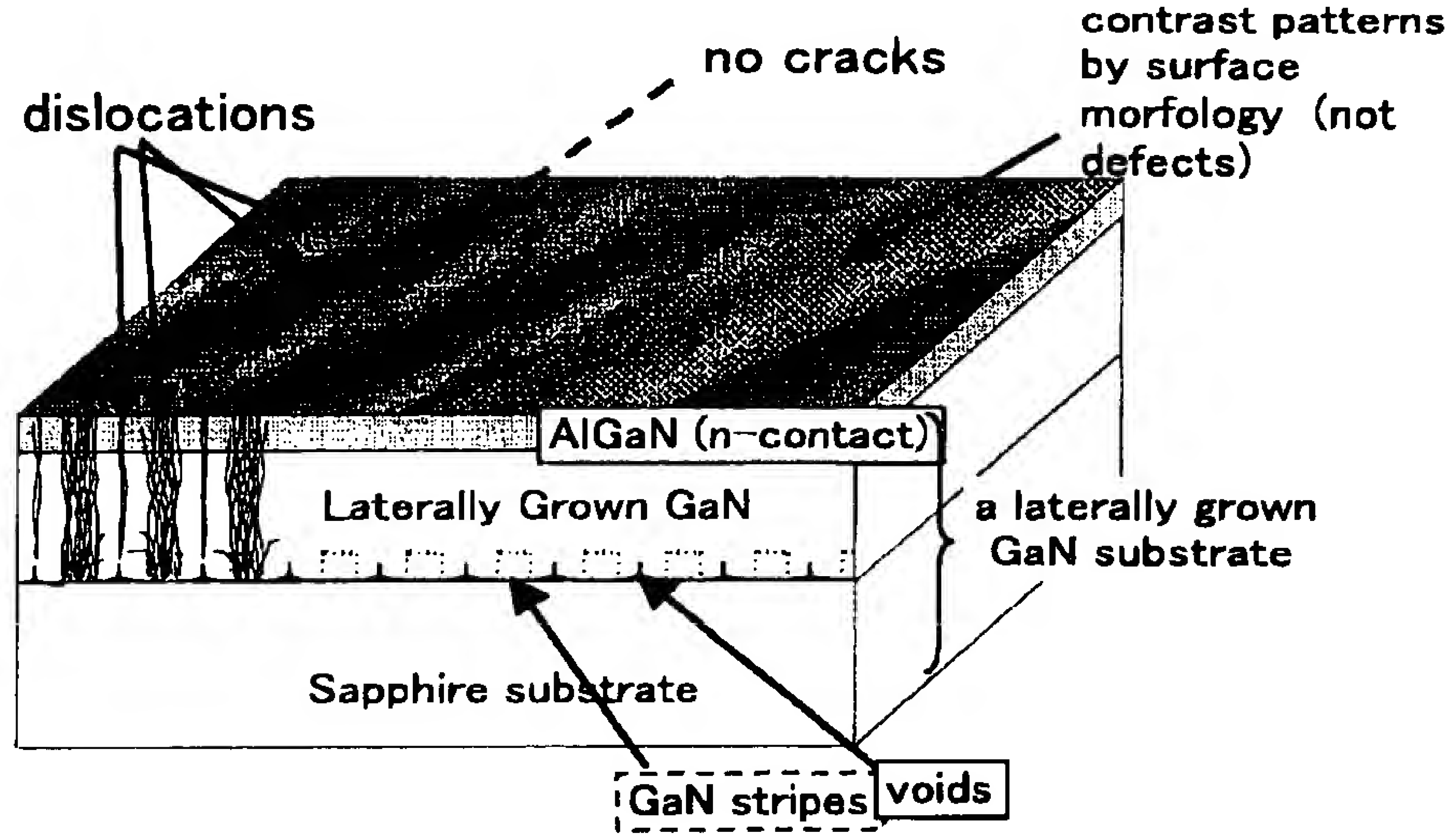
claim 14

nitride semiconductor laser



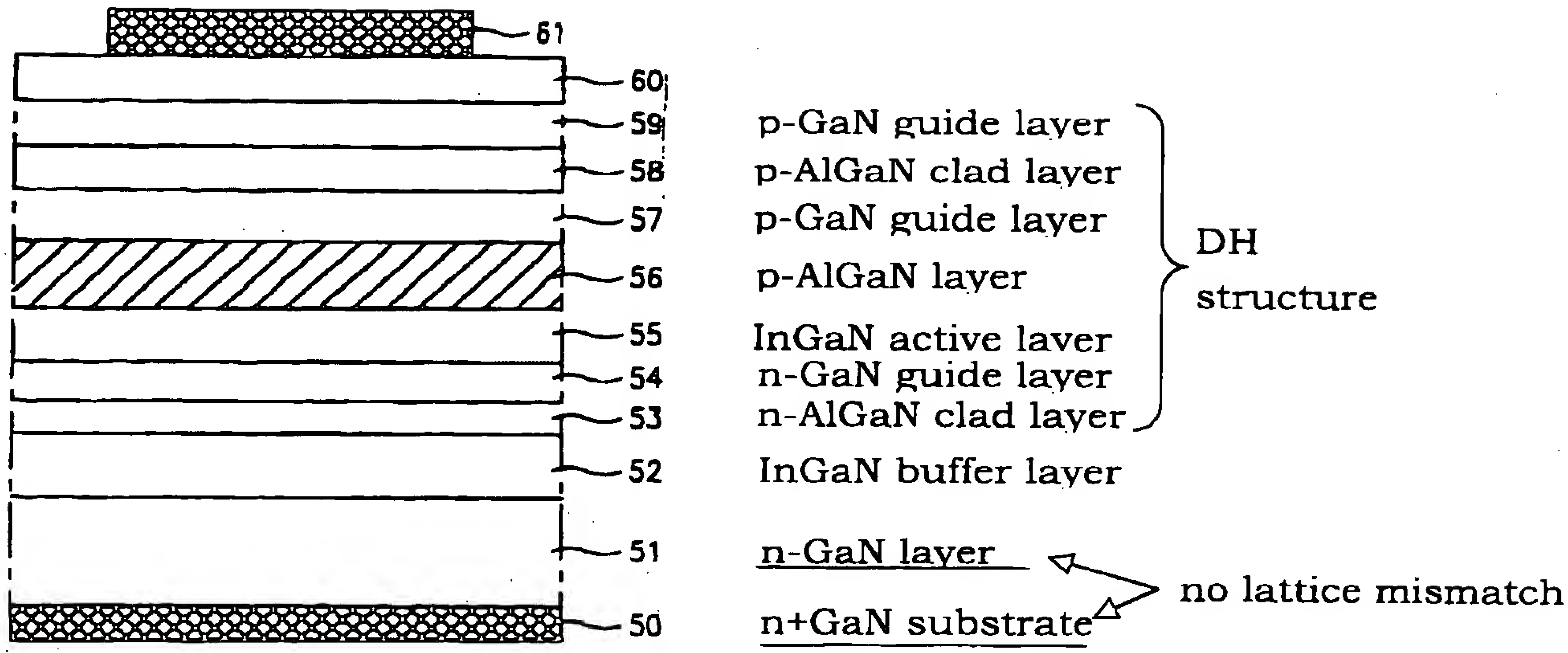
This generates compressive strain in the AlGaN layer and prevents the occurrence of "small cracks" (see Figure D below and attached in color). Thus, the lifetime of the laser is considerably extended.

Figure D (part)



Turning now to the references applied in the current Action, items 2 and 3, Hong et.al (U.S. 6,177,292), a laser structure on a GaN substrate, merely discloses a conventional nitride laser structure on a GaN substrate. For example, Hong describes a GaN-based laser diode as shown below, where a GaN layer 51 is formed on a GaN substrate 50, and, then, an n-type cladding layer 53, an active layer 55 and a p-type cladding layer 58 (= Double Hetero structure) are formed on the GaN layer 51 intervening an InGaN buffer layer 52 (Hong et.al, Seventh and Eighth Embodiment, Fig.6, line 33 of column 8 to line 15 of column 10).

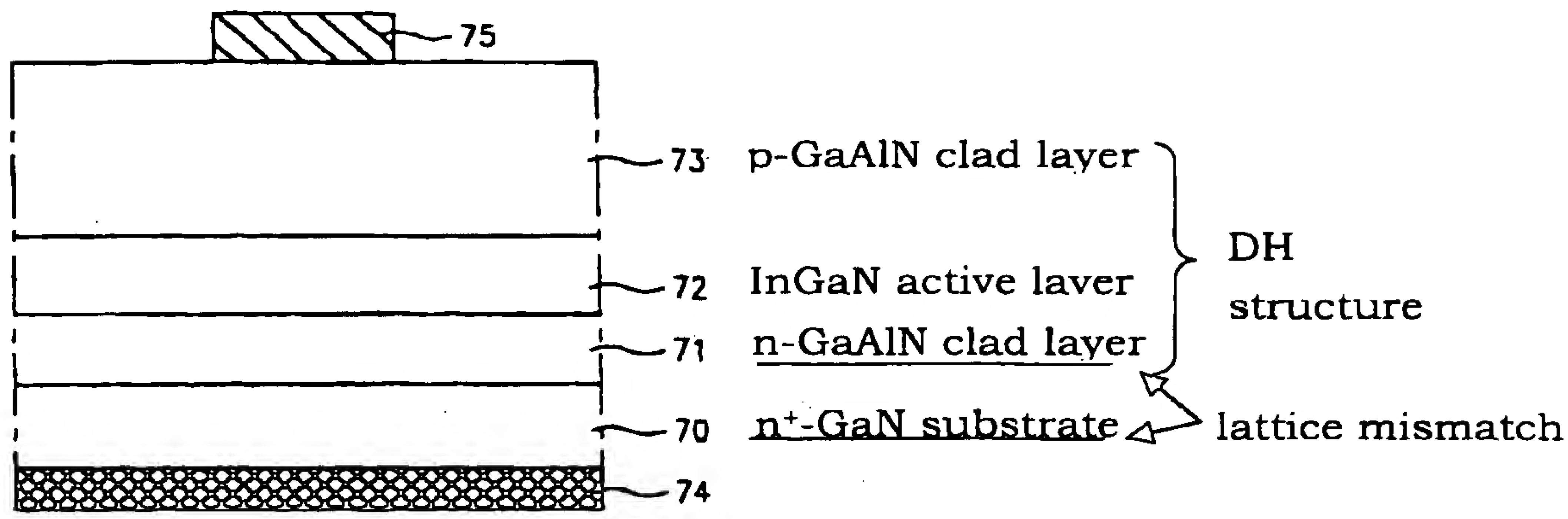
Laser Diode (Hong et.al., Figure 6)



Hong also describes that the formation of the n+-GaN layer 51 on the n+GaN substrate 50 allows high quality epitaxial growth and can solve the fundamental problem caused by the lattice mismatch and the thermal expansion coefficient difference (Hong et.al.,column 9, lines 6 to 13) .

In the Office Action the Examiner directs attention to a passage of Hong that describes forming a AlGaN cladding layer 71 on GaN substrate 70. However, the passage cited is not related to a laser diode but to a light emitting diode (see column 10, lines 17 to 21). Such a construction, as Fig. 7 in Hong, could be employed because the lifetime of light emitting diodes is less sensitive to crystallinity of the cladding layer than is a laser.

Light Emitting Diode (Hong et.al., Figure 7)

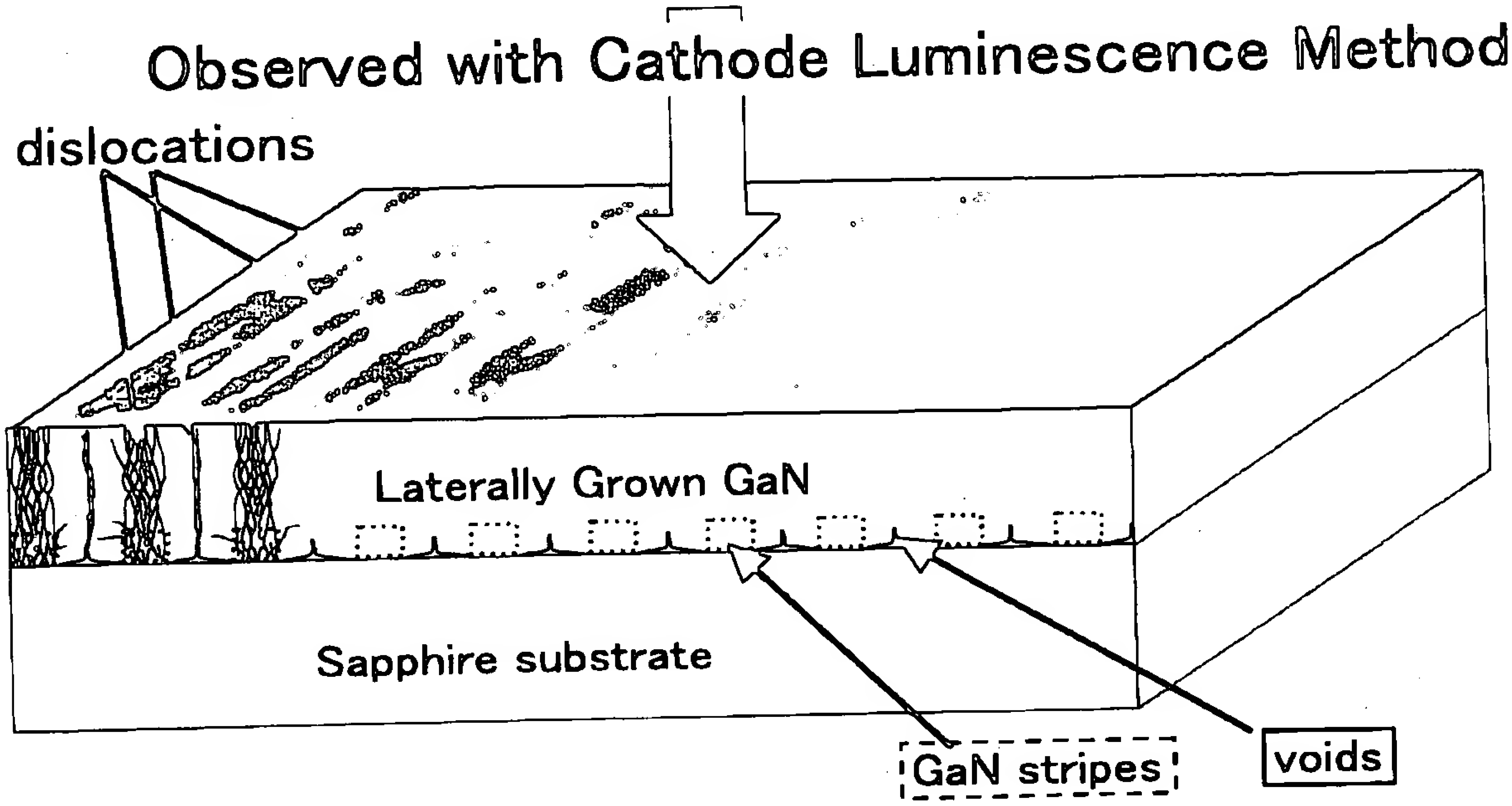


As discussed above, Koide (JP 11-145516) merely discloses a laterally grown GaN substrate using the conventional lateral-growth process. Koide does not teach or suggest or even recognize the "small cracks" or forming an AlGaN layer directly on a laterally-grown GaN substrate.

As explained above, neither Hong nor Koide nor their combination teach or suggest forming AlGaN instead of GaN on a laterally grown GaN substrate for a laser diode. Accordingly, claims 9-16 are not rendered obvious by the cited prior art references.

Figure A (a laterally grown GaN substrate)

sapphire/buffer lay r/stripe GaN layer/laterally grown GqN layer



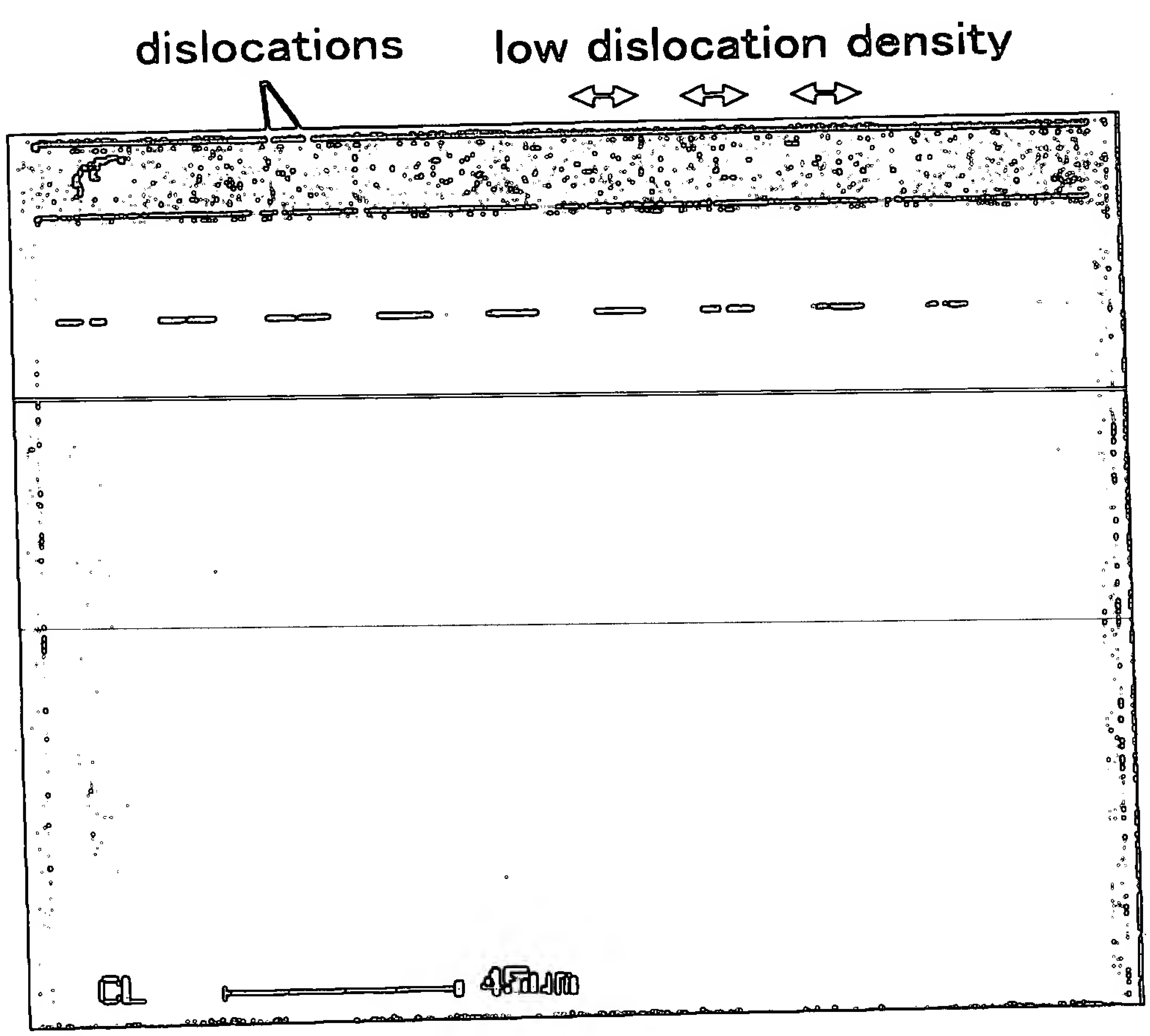
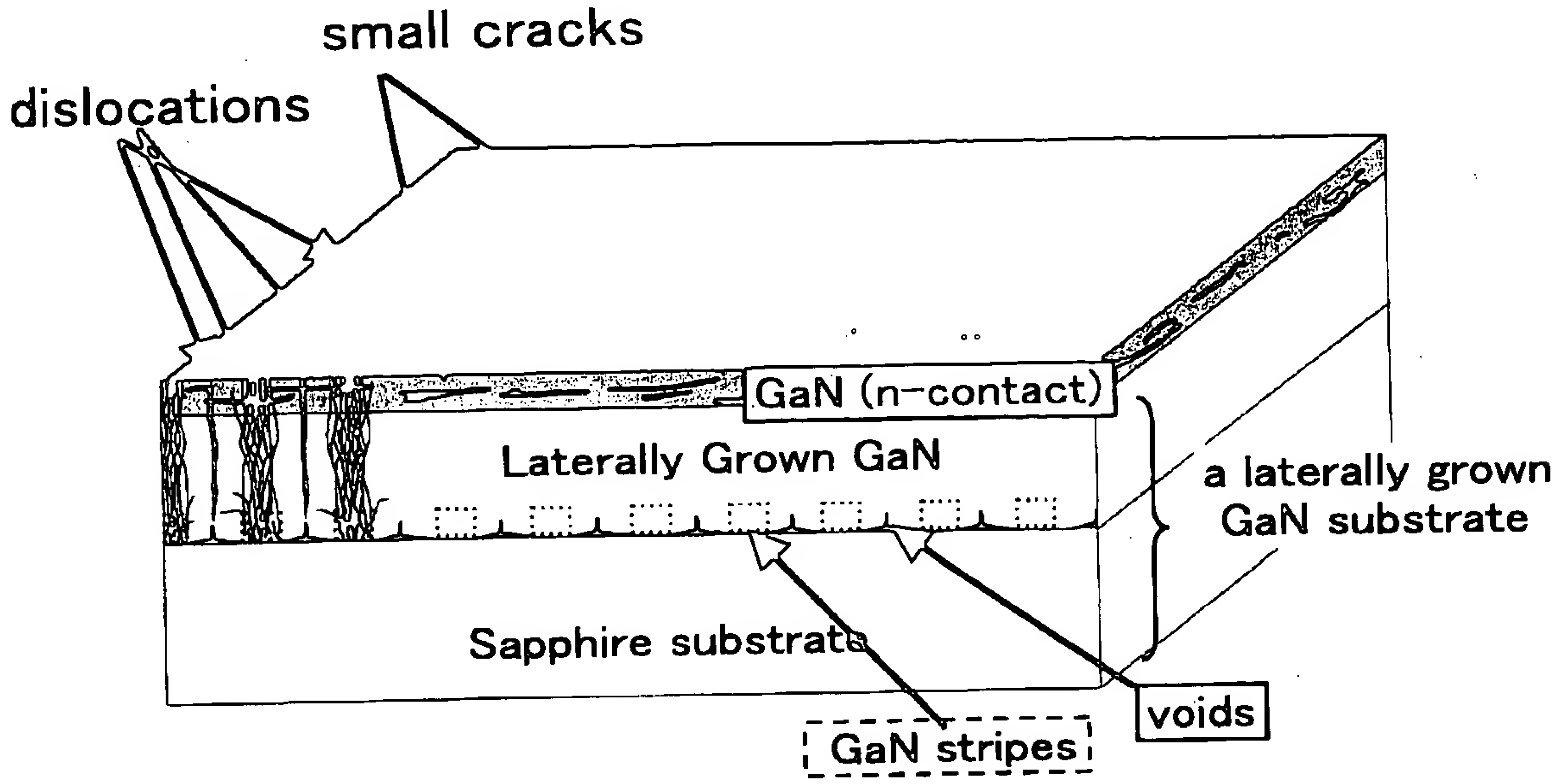


Figure B (a GaN layer on a laterally grown GaN substrate)

sapphire/buffer lay r/GaN strip layer/laterally grwon GaN layer/GaN lay r



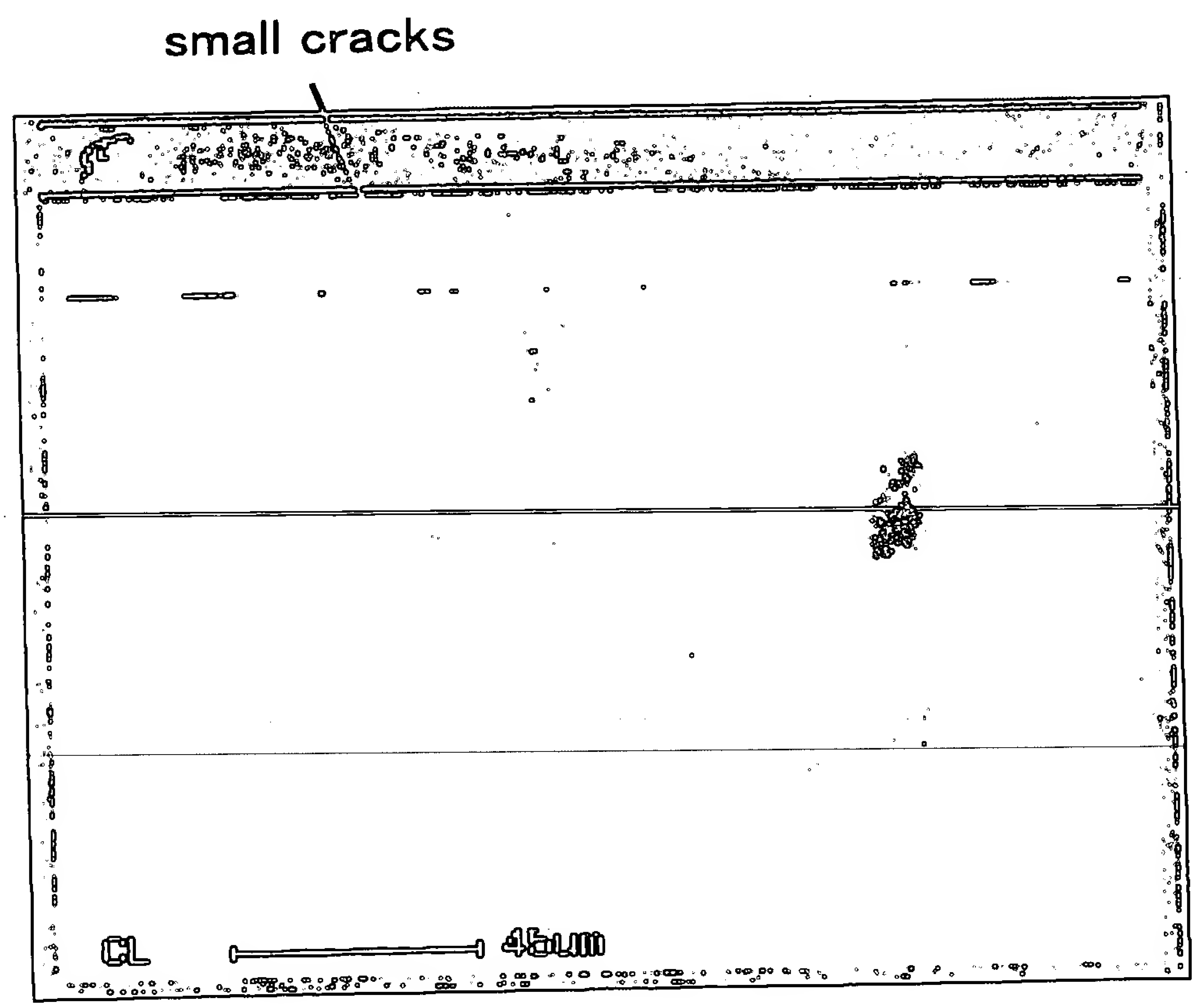
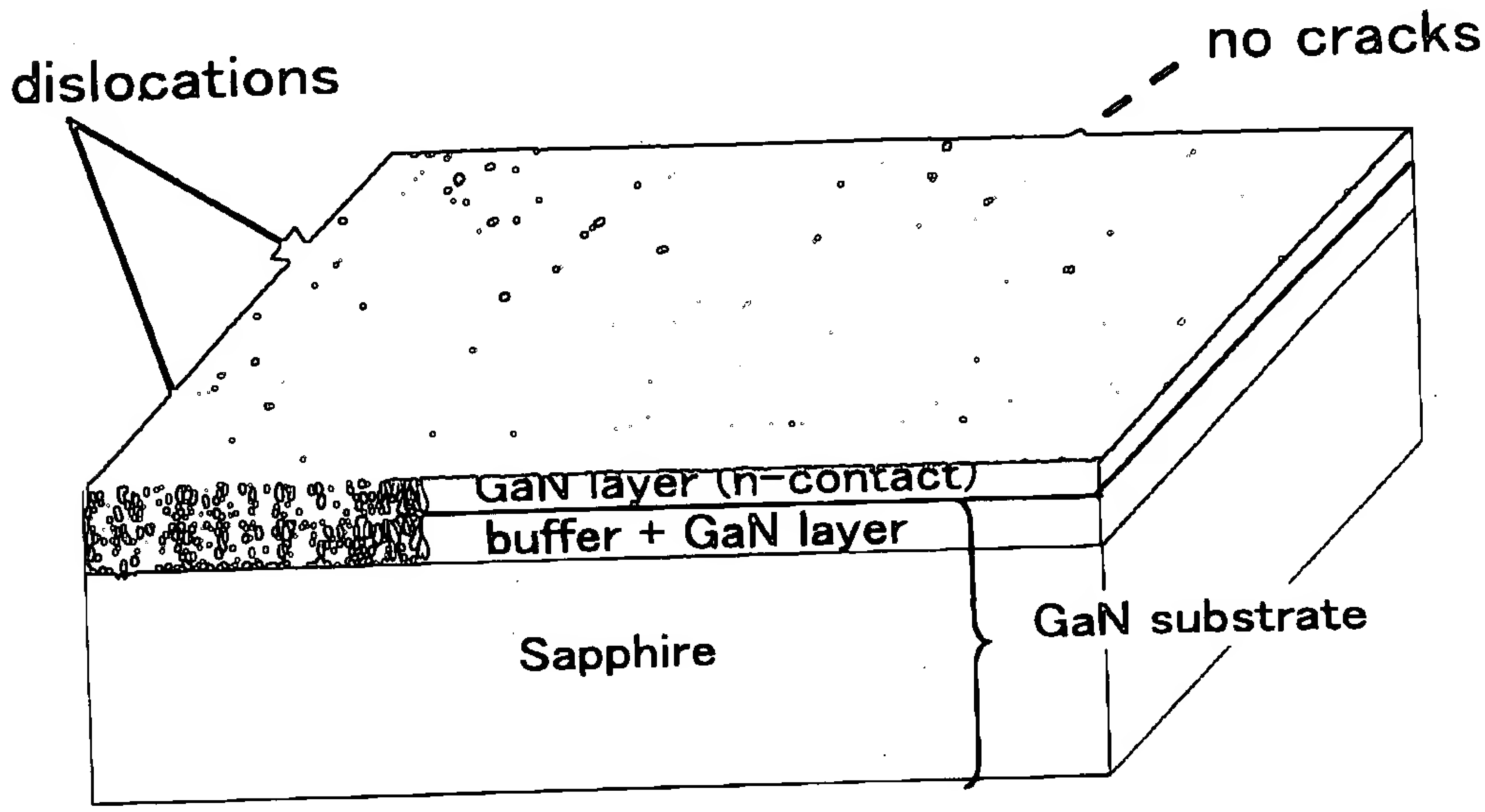


Figure C (a GaN lay r on a normal GaN substrate)

sapphire/buffer layer/GaN layer/GaN layer



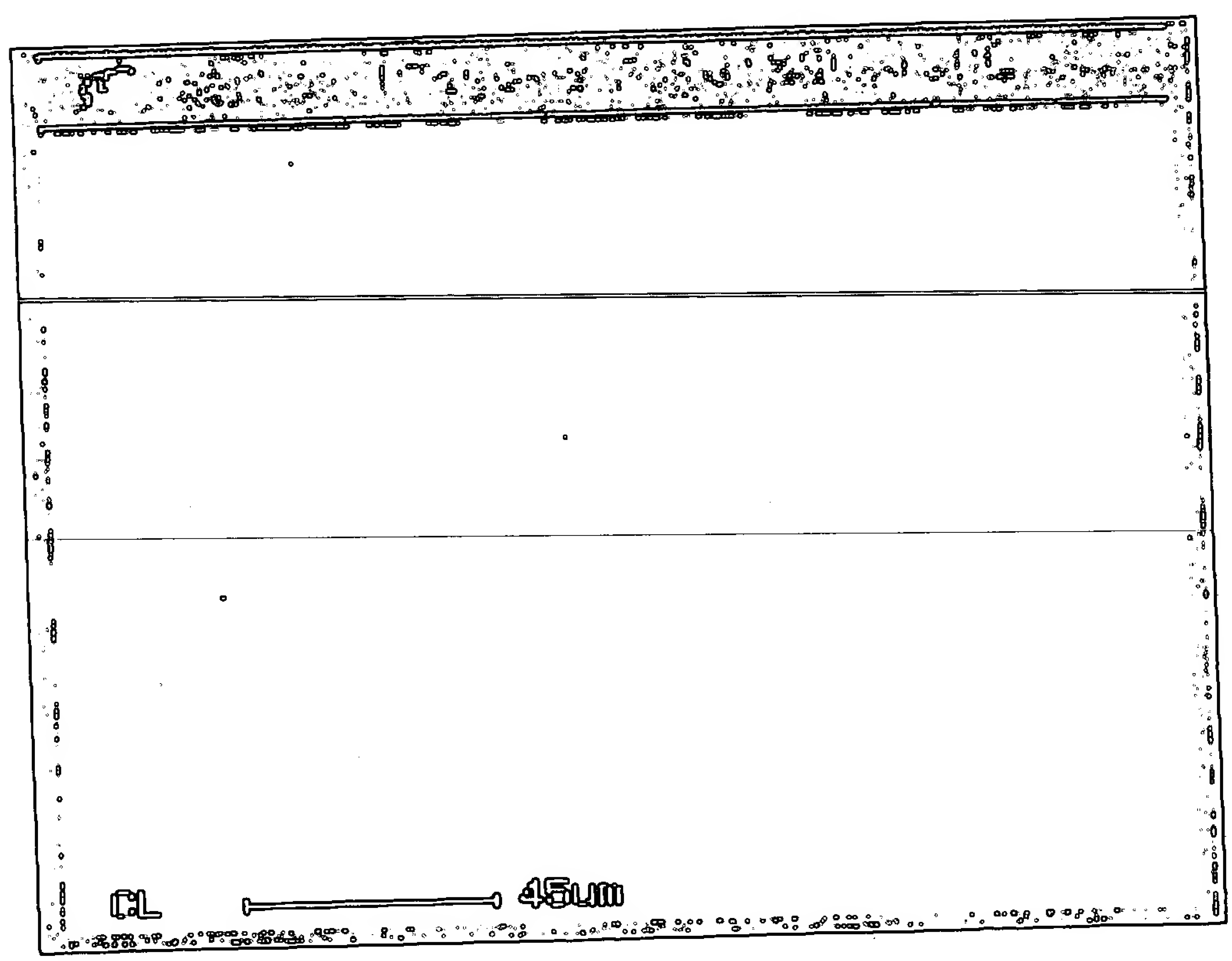
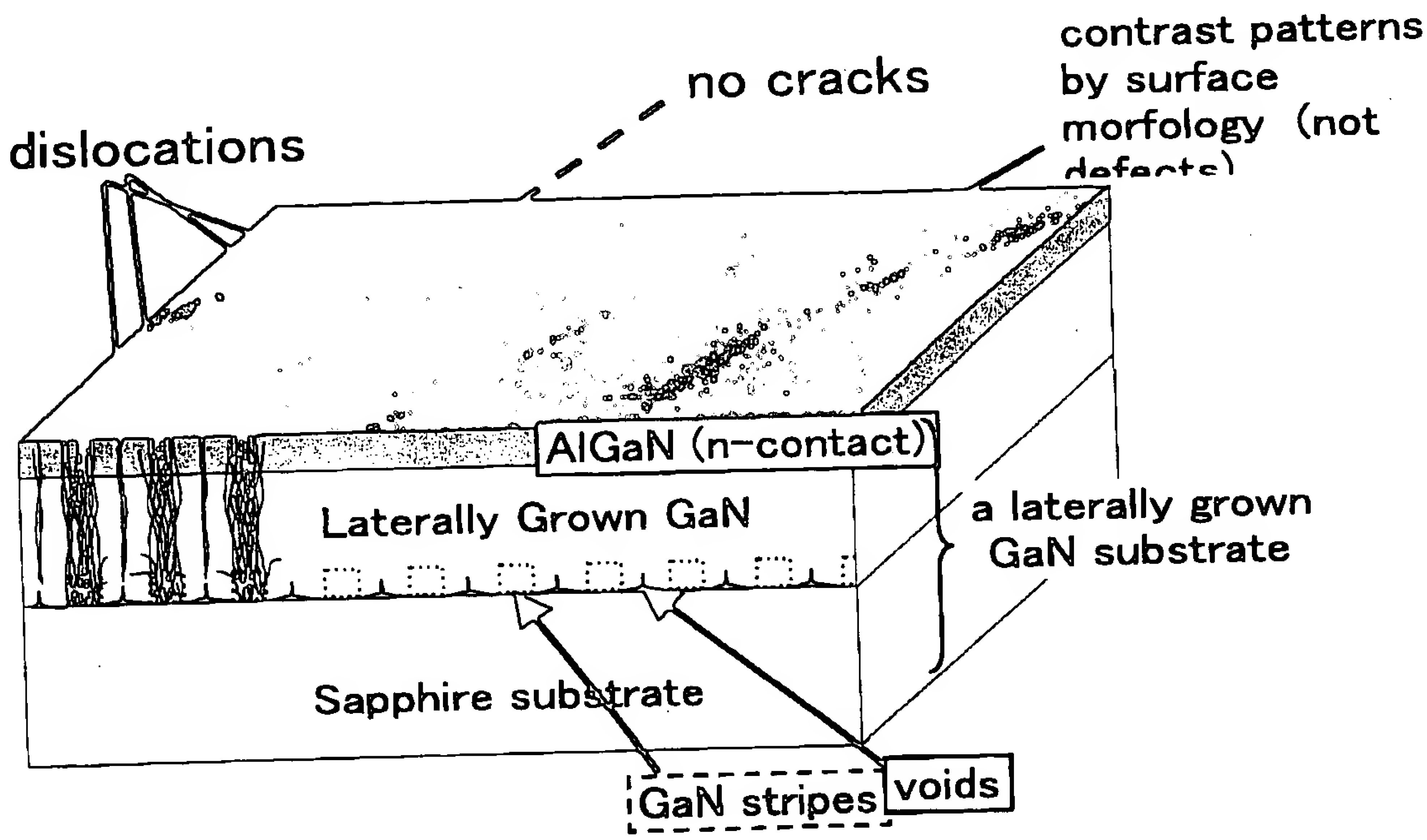
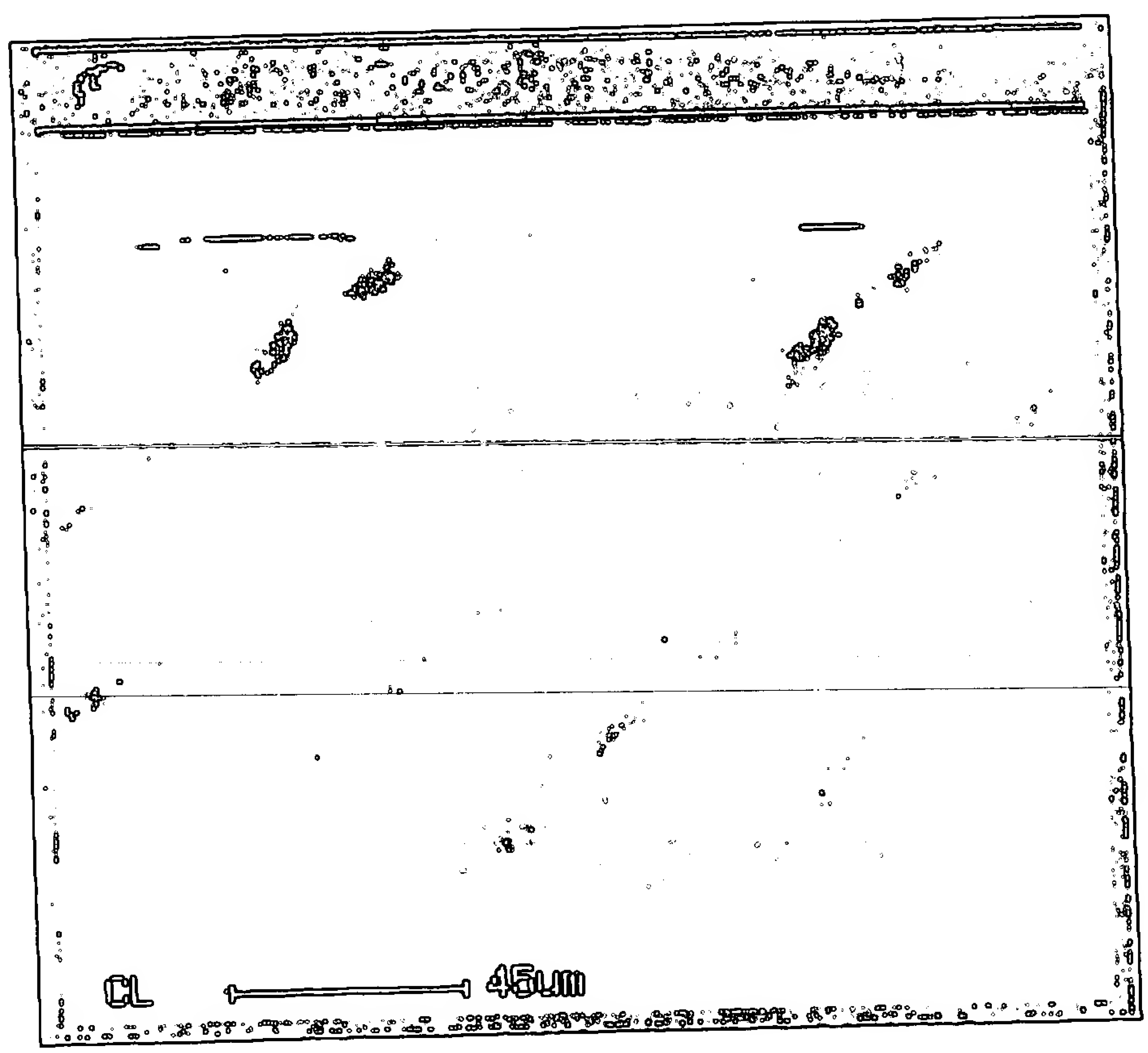


Figure D (an AlGaN layer on a laterally grown GaN substrate)

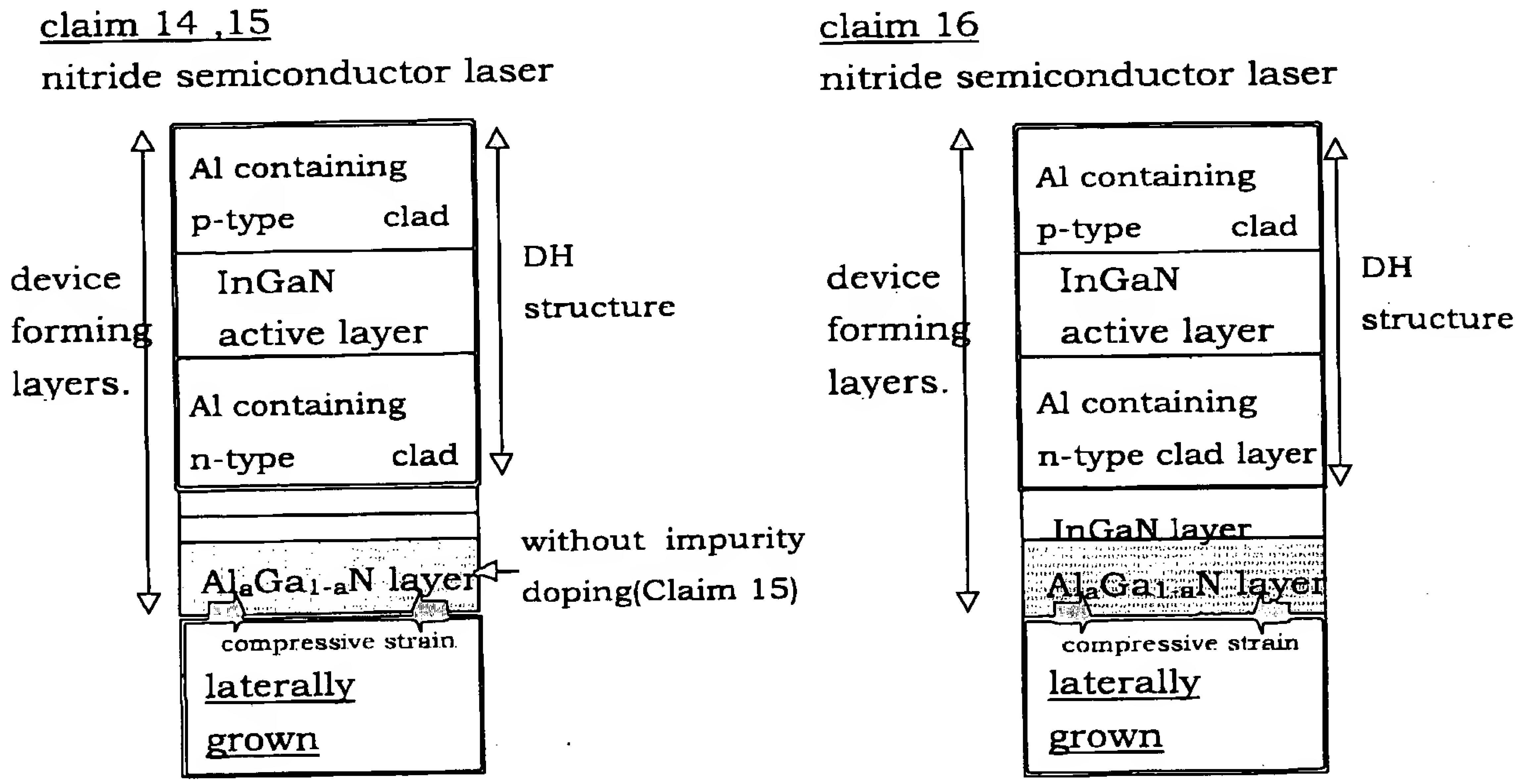
sapphir /buff r layer/GaN stripe layer/laterally grwon GaN layer/AlGaN layer





Claims 14 to 16 are the subject of a separat rejection in item 4 of the Action on the basis of Hong et al (discussed above) in view of Kern et al (U.S. 6,194,742).

The structures of the lasers described in Claim 14-16 are as follows:



<u>Note in Claims 14 to 16, an AlaGa1-aN layer is formed on laterally grown on a GaN substrate before forming an Al-containing n-type clad layer.</u> This structure generates compressive strain in the AlaGa1-aN layer during cooling after the epitaxial growth of the device forming layers, since the thermal expansion coefficient of AlGaN is smaller than that of GaN. This prevents the occurrence of "small cracks" in the AlaGa1-aN layer, which is a specific phenomenon of laterally grown GaN substrates. Thus, the lifetime of the laser is considerably extended.

Claims 14 to 16 are rejected over Hong in view of Kern. However, neither Hong nor Kern teach or suggest the use of a laterally grown GaN substrate, hence even if combined the result would not satisfy the requirements of claims 14-16. Therefore, three references

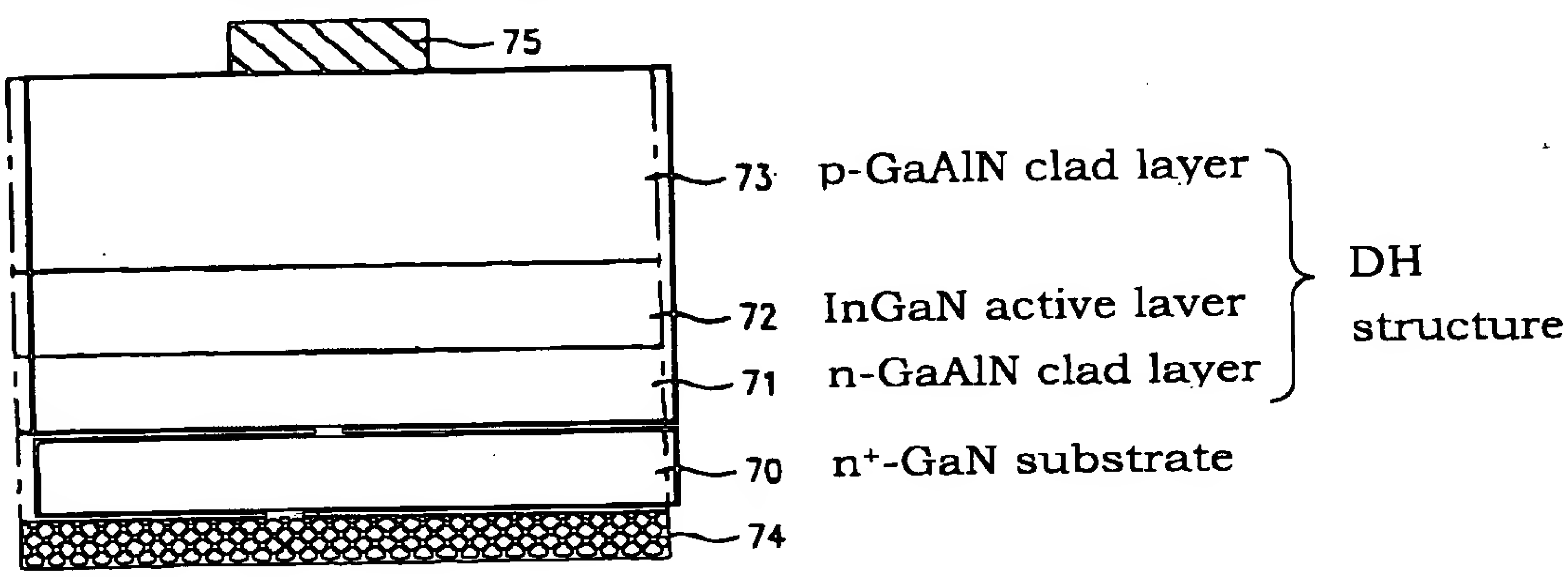
(Hong, Kern and Koide) must be combined to reject Claims 14 to 16. However, there is no suggestion or teaching in the prior art to combine these three references.

Hong et.al, describes a laser structure on a GaN substrate

As described above, Hong et.al. merely discloses a conventional nitride laser structure on a GaN substrate.

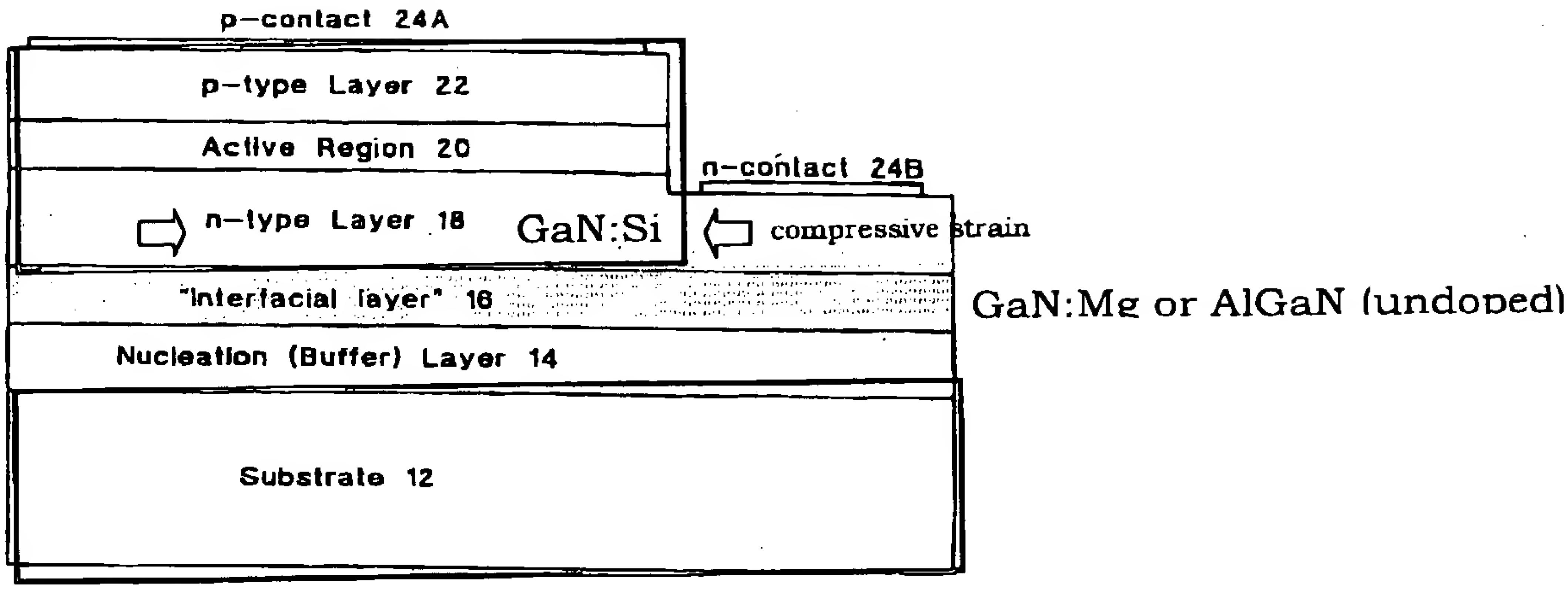
Although the Examiner directs attention to a passage of Hong that describes forming a AlGaN cladding layer 71 on a GaN substrate 70, the passage cited is not related to a laser diode but to a light emitting diode (column 10, lines 17 to 21). Also, this passage of Hong does not disclose forming AlGaN layer on a GaN substrate before forming Al containing n-type clad layer as explained below.

Light Emitting Diode (Hong et.al., Figure 7)



Kern discloses a light emitting diode or laser diode having the following structure:

642979



The Examiner argues that it would have been obvious to one with ordinary skill in the art to provide a device forming (interfacial) layer over Kern's disclosure. However, the AlGaN interfacial layer 16 in Kern is unlike the AlaGa1-aN layer in Claims 14 to 16, and one with ordinary skill in this art would not motivated to form an AlGaN interfacial layer on a GaN substrate in a laser diode of Hong.

First, the AlaGa1-aN layer in Claims 14 to 16 must contact with a laterally grown GaN substrate to prevent the "small cracks", which is a specific phenomenon of laterally grown GaN substrates. On the other hand, the AlGaN interfacial layer 16 in Kern must contact with the n-clad layer 18 to reduce "cracking", which is a normal one and different from the "small cracks". The AlGaN interfacial layer 16 in Kern must contact with the n-clad layer 18, because the interfacial layer 16 in Kern prevent cracking in the n-clad layer 18 by generating compressive strain in the n-type GaN:Si layer 18 (see column 4, lines 17 to 32 of Kern).

Second, the n-clad layer in Claims 14 to 16 must contain Al. In direct contrast, the n-type layer 18 in Kern must be GaN:Si in order to reduce "cracking" by the interfacial layer 16. The AlGaN interfacial layer 16 in Kern reduces "cracking" in the n-type GaN:Si layer 18 by generating compressive strain, which is caused by the difference in lattice constant between GaN and AlGaN. This is apparent from the Kern's statement "for GaN grown on AlGaN, where the AlGaN has a smaller lattice constant than GaN, the GaN layer will be in a state of compression and result in a reduction of cracking" (column 4, lines 29-33 of Kern). Therefore, one with ordinary skill in the art would not be

motivated to introduce Kern's AlGaN interfacial layer 16 into Hong's device, in which n-cladding layer is not GaN but instead AlGaN (see Fig.6 and 7 of Hong).

As explained above, neither Hong nor Kern teach or suggest the features of Claims 14 to 16. Accordingly, claims 14-16 are not suggested by the cited prior art references.